Catenary 전기적 특성
Electrical Characteristics of Catenary

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ABSTRACT

In this paper, the basic requirements of catenary in railroad traction is explained. Three different types of catenary suspension systems for different terrains, environments and high speed / low speed trains are presented. The essential requirements of catenary such as reliability, cost effectiveness, maintenance and ruggedness requirements are discussed. The catenary materials and safety problems associated in it are dealt.

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1. **Introduction:**

There is a wide variety of electric traction systems around the world, which have been built according to the type of railway, its location and the technology available at the time of the installation. Many installations seen today were first built up to 100 years ago, some when electric traction was barely out its diapers, so to speak, and this has had a great influence on what is seen today.

In the last 20 years there has been a gigantic acceleration in railway traction development. This has run in parallel with the development of power electronics and microprocessors/ microcomputers. What have been the accepted norms for the industry for, sometimes, 80 years, have suddenly been thrown out and replaced by fundamental changes in design, manufacture and operation. Many of these developments are highly technical and complex.

To begin with, the electric railway needs a power supply that the trains can access at all times. It must be safe, economical and user friendly. It can use either DC (direct current) or AC (alternating current), the former being, for many years, simpler for railway traction purposes, the latter being better over long distances and cheaper to install but, until recently, more complicated to control at train level.

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Transmission of power is always along the track by means of an overhead wire or at ground level, using an extra, third rail laid close to the running rails. AC systems always use overhead wires, DC can use either an overhead wire or a third rail; both are common. Both overhead systems require at least one collector attached to the train so it can always be in contact with the power. Overhead current collectors use a "pantograph", so called because that was the shape of most of them until about 30 years ago. The return circuit is via the running rails back to the substation. The running rails are at earth potential and are connected to the substation. In this paper, the mechanics of power supply wiring, different types of suspension systems for various conditions, catenary wire details, problems associated with it are dealt.

2. AC or DC traction

It doesn't really matter whether the trains have AC or DC motors, nowadays either can work with an AC or DC supply. We just need to put the right sort of control system between the supply and the motor and it will work. However, the choice of AC or DC power transmission system along the line is important. Generally, it's a question of what sort of railway we have. It can be summarized simply as AC for long distance and DC for short distance. Of course there are exceptions and we will see some of them later. It is easier to boost the voltage of AC than that of DC, so it is easier to send more power over transmission lines with AC. This is why national electrical supplies are distributed at up to 765,000 volts AC. As AC is easier to transmit over long distances, it is an ideal medium for electric railways. Only the problems of converting it on the train to run DC motors restricted its widespread adoption until the 1960s.

DC, on the other hand was the preferred option for shorter lines, urban systems and tramways. However, it was also used on a number of main line railway systems, and still is in some parts of continental Europe, for example. Apart from only requiring a simple control system for the motors, the smaller size of urban operations meant that trains were usually lighter and needed less power. Of course, it needed a heavier transmission medium, a third rail or a thick wire, to carry the power and it lost a fair amount of voltage as the distance between supply connections increased. This was overcome by placing substations at close intervals every three or four kilometers at first, nowadays two or three on a 750 volt system compared with every 20 kilometers or so for a 25 kV AC line.

It should be mentioned at this point that corrosion is always a factor to be considered in electric supply systems, particularly DC systems. The tendency of return currents to wander away from the running rails into the ground can set up electrolysis with water pipes and similar metallic. This was well understood in the late 19^{th} Century and was one of the reasons why London's Underground railways adopted a fully insulated DC system with a separate negative return rail as well as a positive rail - the four-rail system. Nevertheless, some embarrassing incidents in Asia with disintegrating manhole covers near a metro line as recently as the early 1980s means that the problem still exists and isn't always properly understood. Careful preparation of earthing protection in structures and tunnels is an essential part of the railway design process and is neglected at one's peril.

3. Overhead Line (Catenary)

The mechanics of power supply wiring is not as simple as it looks (diagram, left). Hanging a wire over the track, providing it with current and running trains under it is not that easy if it is to do the job properly and last long enough to justify the expense of installing it. The wire must be able to carry the current (several thousand amps), remain in line with the route, withstand wind (in Hong Kong typhoon winds can reach 240 km/h), extreme cold (Korea) and heat (India) and other hostile weather conditions. Overhead catenary systems, called "catenary" from the curve formed by the supporting cable, have a complex geometry, nowadays usually designed by computer. The contact wire has to be held in tension horizontally and pulled laterally to negotiate curves in the track. The contact wire tension will be in the region of 2 tones. The wire length is usually between 1000 and 1500 meters long, depending on the temperature ranges. The wire is zigzagged relative to the centre line of the track to even the wear on the train's pantograph as it runs underneath.

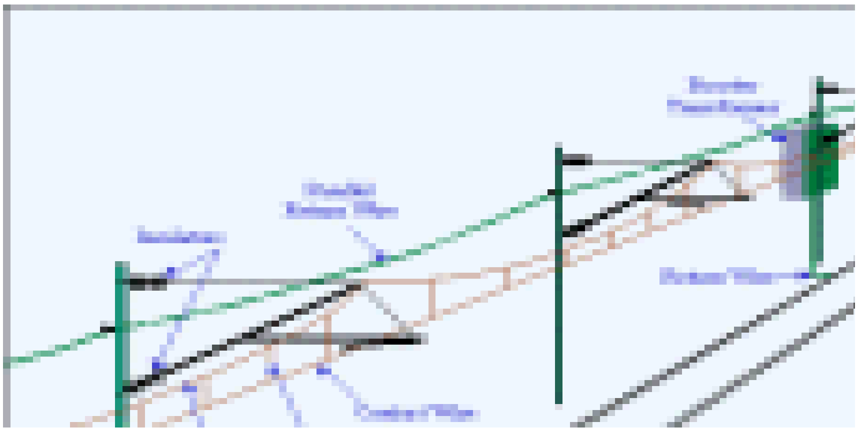

Fig. 2.1 Overhead line

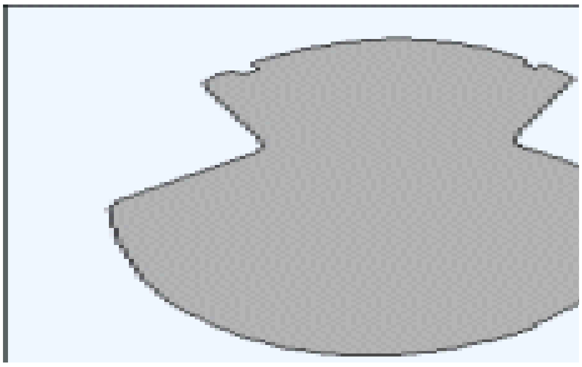

Fig. 2.2. Cross-section of overhead line

The contact wire is grooved to allow a clip to be fixed on the top side. The clip is used to attach the dropper wire. The tension of the wire is maintained by weights suspended at each end of its length. Each length is overlapped by its neighbour to ensure a smooth passage for the "pan". Incorrect tension, combined with the wrong speed of a train, will cause the pantograph head to start bouncing. An electric arc occurs with each bounce and a pan and wire will soon both become worn through under such conditions. More than one pantograph on a train can cause a similar problem when the leading pantograph head sets up a wave in the wire and the rear head can't stay in contact. High speeds worsen the problem. The French TGV (High Speed Train) formation has a power car at each end of the train but only runs with one pantograph raised under the high speed 25 kV AC lines. The rear car is supplied through a 25 kV cable running the length of the train.

This would be prohibited in Britain due to the inflexible safety approach there.

A waving wire will cause another problem. It can **cause the dropper wires, from which the contact wire is hung, to "kink" and form little loops.** The contact wire then becomes too high and aggravates the poor contact.

Fig. 2.3 Waving wire

Overhead lines are normally fed in sections like 3rd rail systems, but AC overhead sections are usually much longer. Each subsection is isolated from its neighbor by a section insulator in the overhead contact as shown in this picture below. The subsections can be joined through special high speed section switches. To reduce the arcing at a neutral section in the overhead catenary, some systems use track magnets to automatically switch off the power on the train on the approach to the neutral section. A second set of magnets restores the power immediately after the neutral section has been passed. The next photo shows a set of track magnets.

Fig. 2.4 Track Magnets.

3.1 Catenary Suspension Systems

Various forms of catenary suspension are used (see diagram below), depending on the system, its age, its location and the speed of trains using it. Broadly speaking, the higher speeds, the more complex the "stitching", although a simple catenary will usually suffice if the support posts are close enough together on a high speed route. Modern installations often use the simple catenary, slightly sagged to provide a good contact. It has been found to perform well at speeds up to 125 m/hr (200 km/hr).

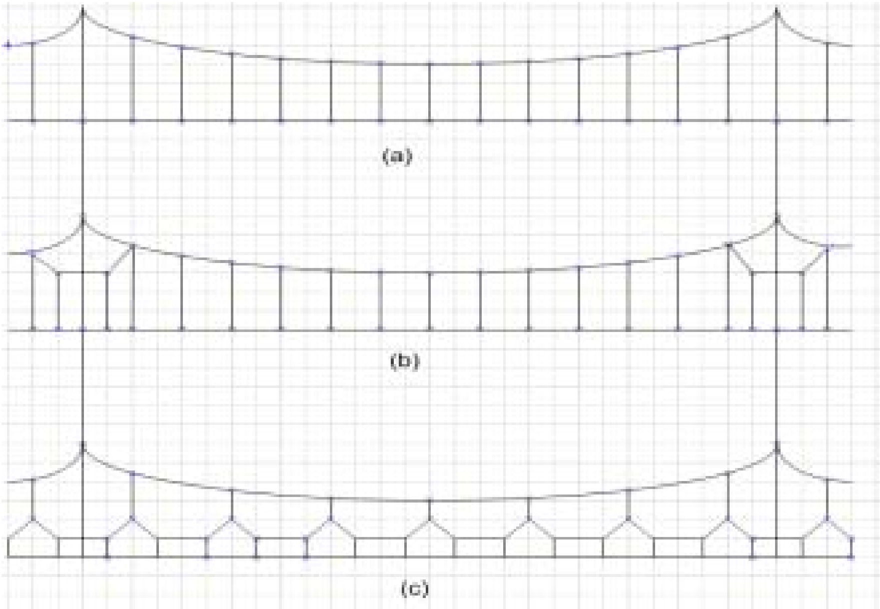

Fig. 3.1 Types of catenaries (a) Simple, (b) Sagging, (c) Complex

At the other end of the scale, a tram depot may have just a single wire hung directly from insulated supports. As a pantograph passes along it, the wire can be seen to rise and fall. This is all that is necessary in a slow speed depot environment. DC overhead wires are usually thicker and, in extreme load cases, double wires are used, as in Hong Kong Mass Transit's 1500 v DC supply system. Up to 3000 volts overhead is used by DC main line systems (e.g. parts of France, Belgium and Italy) but below 1500 volts, a third rail can be used. In operating terms, the third rail is awkward because of the greater risk of it being touched at ground level. It also means that, if trains are stopped and have to be evacuated, the current has to be turned off before passengers can be allowed to wander the track. Third rail routes need special protection to be completely safe. On the other hand, some people consider the overhead catenary system a visual intrusion. Singapore, for example, has banned its use outside of tunnels.

3.2 Catenaries

In general all railways use catenaries of the constant-tension type. At one end of each section of the catenary the cable goes over a pulley and is terminated by a hanging weight. The pulley and weight combination ensures that the catenary cable maintains the same tension regardless of the ambient temperature and the consequent expansion or contraction of the cable. This avoids problems with the catenary sagging too much in hot weather, or, if the tension is too high, snapping in cold weather.

Further, it is important that the tension be within certain precise bounds for mechanical reasons: the moving pantograph creates a shock wave in the catenary that travels along the cable; its speed is determined by the tension in the catenary, and if it is less than the speed of the pantograph, the cable will be prone to buckling and snapping. The pressure of the pantograph pan against the contact wire is usually around 6.5kg/cm^{2}on IR. The equivalent copper cross-section of the catenary is usually about 157 to 165 sq. mm. (65 sq. mm. stranded copper-cadmium catenary and 107 sq. mm. grooved copper contact wire). On a single-track section, this allows a current of up to 600A to be drawn from the catenary without raising its temperature to more than about 85°C, which is the safe upper limit to avoid risks of fire, equipment failure, etc., and to maintain the physical properties of the catenary within acceptable bounds.

DC traction sections have much higher equivalent cross-sections because of the higher current drawn (as the voltage is about 1/16 that of AC sections, the current is correspondingly higher, necessitating a total catenary cross-section about 4 times that used on AC sections). Typically, the equivalent cross-section for DC catenaries is about 645 sq. mm (323 sq. mm primary catenary cables, 129 sq. mm auxiliary catenary, and 193 sq. mm contact wire).

As mentioned earlier, the catenary in fact consists of more than one cable; the one that actually touches the pantograph and carries the current is the **contact wire**. The contact wire may be suspended directly from the cantilever arms from the support posts (this is not common, and is only found on low-speed sections and turnouts). More often, the contact wire is suspended from another wire called the **messenger wire**. The messenger is the one that assumes the typical catenary (hyperbolic cosine) curve shape. The contact wire is suspended from the messenger by vertical **risers** or **spacers**. A third wire, the **auxiliary cable** may appear between the messenger and the contact wire although this design is rare in India. The contact wire is usually grooved on the sides, so that it can be gripped firmly from the sides without creating any discontinuity on the lower surface where the pantograph rubs against it. It is usually made of hard-drawn copper, although sometimes copper alloys have been used. The other part -- the catenary cable -- is made up of multiple strands of copper, or more often, a copper-cadmium alloy. In 1990, Indian Railways experimented with installing aluminium contact wire catenary on a 260km section. This proved to be unworkable because there were too many defects caused by oxidation and mechanical failure (strand breakage) in the wire, and the aluminium cables were replaced by standard copper-cadmium wires by 1998. The messenger wire is usually of an alloy chosen more for its mechanical properties.

3.3 Catenary Height

The contact wire is generally at about 5.5m from the rail level. The minimum height is around 4.8m (e.g., under bridges or overpasses, etc.). In yards, in sheds or lines leading up to sheds, etc., the catenary contact wire may be higher; 5.8m is a typical height. At the end of each section of catenary, a new section begins, with the old and new catenaries running in parallel for a short distance. On BG routes, this switch from one catenary to another usually happens over a length corresponding to 4 catenary masts, with the old and new catenaries overlapping (running parallel) for about 50m. On MG, this is usually accomplished over a length corresponding to 3 catenary masts, with one catenary taking off immediately after the point where the other stops.

When successive sections of the AC catenary are supplied by different phases from the 3-phase power grid, there is a short, electrically neutral (un-energized) section (**dead zone** or **neutral section**) of catenary that comes between them. The loco has to coast through this 'phase break' with a brief interruption in the supply of power. Sometimes different sections of the catenary are connected to different phases at different times and the neutral sections may be a **switched neutral section**. (The term also refers to neutral sections at AC-DC switchover points where the neutral section can be switched to either the AC or the DC supply, and is also known as the **dynamic neutral section**.)

3.4 Transmission voltage

Power is transmitted to the electrical substations at 750kV, 220kV, 132kV, or 110kV and then stepped down as required to 25kV or 50kV. The power from the grid is usually in the form of 3 phase power.

3.5 Catenary voltage

In practice, the catenary voltage in the 25kV AC system can vary from something like 18kV to over 30kV because of poor regulation at the substation or incorrect configurations of the transformers, etc. Most locos are designed to handle a certain range of catenary voltages, although of course the operation may be less than optimal at voltages far from the norm.

4. Conclusions

AC tractions are preferred for long distance heavy duty trains and DC for short distance light weight usually for metro train services. Catenary wire length and thickness are functions of temperature range, speed of the train and unforeseen natural calamities. Three different type's catenary suspension systems are in use and their uses differ from country to country. Stranded copper cadmium catenary wire is recommended for long life, heavy current less wear and tear.

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